wonder if any of you really doubt that every notion in physics, definite or indefinite, is associated with and derived from a physical operation, and that absolutely the only way to teach physics to young men is to direct their attention to that marvelous series of determining operations which bring to light those one-to-one-correspondences which constitute the abstract facts of physical science. If you do, I am bound to say I do not think much of your knowledge or teaching of physics. I think that the sickliest notion of physics, even if a student gets it, is that it is 'the science of masses, molecules and the ether.' And I think that the healthiest notion, even if a student does not wholly get it, is that physics is the science of the ways of taking hold of bodies and pushing them!

W. S. FRANKLIN.

INCOMPLETE OBSERVATIONS.*

IN scientific literature many observations are recorded which, from the experimental proof offered, have been generally recognized as true, but which may be classed as *incomplete*, owing to the fact that the methods of investigation employed destroyed conditions that were later found to exist, or that subsequent discoveries modified the conclusions reached at the time of the original investigation.

As an illustration of this proposition the theories of alcoholic fermentation may be cited. The members of Section C will readily recall the long and bitter controversy which was waged between the two great masters, Liebig and Pasteur, and their respective adherents as to the true cause of this phenomenon.

It is interesting at this time, in the light of recent observations, to compare the two opposing theories.

According to Liebig alcoholic fermentation is caused by the decomposition of complicated nitrogenous bodies designated by him as putrescible material, and the molecular disturbance thereby produced is imparted to the fermenticible substance, sugar, and breaks it up into simpler bodies, alcohol and carbon dioxide.

The vitalistic theory, revived by Pasteur and brought to general recognition by his masterly and convincing experiments, teaches that alcoholic fermentation takes place only in the presence of a living micro-organism known as the yeast plant, and that the phenomenon of fermentation is intimately connected with the life process of this organism. The most convincing proof in support of the vitalistic theory was furnished by Pasteur in his methods of preventing fermentation and allied phenomena by simply heating perishable bodies to a temperature high enough to kill the living germs. In the case of acetic acid fermentation he showed that a temperature of 60° was sufficient to destroy the vinegar plant. At this temperature, he argued, the nitrogenous bodies, which Liebig claimed as the actual ferments, would remain intact. In spite of this, however, he showed that further fermentation was completely arrested so long as living germs were excluded.

Although the work of Pasteur was of the greatest importance to science and humanity, and his experimental evidence for the establishment of the vitalistic theory of fermentation was of the highest order, yet to the minds of many it was never entirely clear that the rival theory was completely overthrown. For a long time, however, the vitalistic theory had clear sailing. But the observations which led to its adoption remained incomplete until a few years

*Address of the Chairman of Section C and Vice-President of the American Association for the Advancement of Science, read at the Washington meeting, December 29, 1902.

ago Buchner startled the scientific world by the announcement that he had produced alcoholic fermentation without the presence of a single living germ. By simply mixing the extract, obtained by strong pressure from brewer's yeast, containing nothing but *dead* organic matter, he caused a solution of grape sugar to ferment, and, in fact, much more rapidly than if the yeast itself had been employed. Not only this—Buchner showed, furthermore, that the activity of this extract was completely destroyed at a temperature below that required to kill the yeast plant. This is the important point in Buchner's observations, because it was the failure to recognize this fact by Pasteur and his adherents that helped, more than anything else, to give the death blow to Liebig's theory. It is true that Liebig at first did not regard his putrescible matter or ferments as a product of the ever-present organisms, and it is also true that in Buchner's extract it is the enzyme of the yeast plant which produces the molecular disturbance that causes the grape sugar to break up into alcohol and carbon dioxide; yet it is gratifying to all those who were students of the great master to learn that, in the main, his attitude toward the process of fermentation has been finally vindicated.

It was the desire of the writer to discuss on this occasion some subject related to that branch of chemistry with which he is at present identified, and for this purpose the investigations in regard to assimilation of free nitrogen by plants were selected for consideration, since this question belongs in the category of 'incomplete observations.'

The importance to agriculture of knowing whether plants were capable of assimilating the free nitrogen of the air was impressed upon the minds of the early investigators of the subject of plant nutrition, because if this element in the free state so liberally supplied by nature should be found to be available as plant food, then it would fall into the same class with carbon, hydrogen and oxygen, which furnish the bulk of all vegetable matter, and about whose source the farmer need have no concern. In the early fifties the French chemist, Boussingault, conducted his memorable experiments with various kinds of plants in order to settle this question. His apparatus consisted of a large glass, one-necked globe, into which he introduced a sufficient quantity of soil freed from nitrogen compounds by ignition. In this soil he planted a certain number of seeds, supplied a sufficient amount of water and then hermetically sealed into the neck of the globe a smaller one filled with carbon dioxide. Under this arrangement the seeds were allowed to germinate and the plants to grow. After a period of several weeks the plants with their roots were carefully removed, dried, weighed and the nitrogen determined. He then determined the nitrogen in a like number of seeds themselves and compared the results. Out of fourteen experiments with various kinds of plants, including the legumes, he found in eleven cases a minus quantity of nitrogen in the plants and in the other three a small plus quantity. The latter results, however, he considered within the limits of errors of observation. His conclusion, therefore, was that the free nitrogen was not available plant food.

At the same time another French chemist, Ville, investigated this problem. His experiments were made on a somewhat larger scale, his apparatus consisting of iron sash filled with glass. Ville uniformly found a marked increase in the content of nitrogen of the plants over that of the seeds, and since nitrogen compounds had been excluded during the time of his experiments, he concluded that the source of

this increase was necessarily the free nitrogen of the air. His objection to Boussingault's conclusions was based upon the claim that, in the confined space in which the plants were forced to grow, their natural development was hindered.

Ville's criticism led Boussingault to repeat his experiments. In order to meet the former's objection to the limited amount of air in which the plants were forced to vegetate, he substituted a three-necked globe for the one employed before. By using an aspirator the air in this globe could be continually renewed, after passing it through a series of Wolf's bottles with the proper solutions to free it from nitrogen compounds. The results of this second series of experiments fully corroborated his former conclusions.

A committee appointed by the French Academy of Sciences to investigate the methods employed by Boussingault and Ville held that, in the latter's experiments, the introduction of nitrogen compounds was not excluded, and, therefore, pronounced in favor of Boussingault. If any doubt had remained in regard to the correctness of Boussingault's conclusions it was dispelled a few years later by the labors of Laws, Gilbert and Pugh. These investigators repeated the experiments of Boussingault with expensive and improved apparatus. Their work was performed with the greatest care and nicety, and their results fully vindicated Boussingault in the position he had taken.

The experimental evidence thus produced in favor of the proposition that the free nitrogen of the air was not available for vegetable growth was so clear and convincing that it was readily accepted by all, with the exception of one man. This man was George Ville, of France.

During all the time in which this opinion prevailed, he alone remained firm in the belief that his observations were true, and that plants could assimilate free nitrogen.

That plants can not assimilate free nitrogen directly was established by those early investigators without a doubt. On the other hand, it is now equally well established that free nitrogen does become available as plant food and plays an important part in vegetable production.

Evidently, therefore, the early investigations must have been incomplete, and at this distant day it is not difficult to point out wherein they were defective. Boussingault and Ville, as well as Laws, Gilbert and Pugh, regarded the soil as a mixture of mineral matter and humus. They had no conception of the fact that it was the home of a world of living microorganisms, which in a variety of ways are silently and incessantly active in the transformation of matter essential to vegetable growth. Hence it is but natural that, in preparation of soil free from nitrogen compounds of all kinds, they should, what any chemist under like conditions would do, subject their soil to an intense heat.

Notwithstanding the prominence of these investigators and the general recognition accorded to their conclusions, further work in this connection was at most only retarded but not entirely abandoned. Facts known at that time, and new observations gradually made in studying the soil in all of its phases, began to point in the opposite direction.

With the discovery of Berthelot, that the fixation of free nitrogen took place through the instrumentality of silent electrical discharges in the soil, were associated the manifold effects upon matter, shown to be due to the action of bacterial life. These latter discoveries may be divided into two groups:

1. Those showing the independent action of bacteria in the soil in causing fermenta-

tion, nitrification, denitrification and fixation of free nitrogen.

2. Those showing the fixation of free nitrogen by microbes in symbiotic relation to higher plants.

The first group of observations including the fixation of free nitrogen in the soil as pointed out by Berthelot and others is of great importance to agriculture, but the amount of available nitrogenous plant food produced by the various processes discovered is not sufficient for the demands of intensive farming. The truth of this statement can be inferred from the fact that, in addition to the enormous amount of nitrogenous material obtained from domestic and industrial sources, as well as from the extensive deposits of guano, there are, at the present time, about one million tons of Chili saltpeter employed annually by farmers the world over to maintain partially the fertility of their fields.

The second group of observations are of greater interest to agriculture, since they point out the way of securing from the free nitrogen of the air an ample amount of combined nitrogen to meet all the requirements of intensive farming. They make the farmer independent of the natural deposits of nitrogenous fertilizers, and furnish him the means of preventing his helplessness, in case these sources of plant food should become exhausted or otherwise unavailable.

From the time of the ancients down to the present day the legumes, especially the clovers, have occupied a unique position among agricultural crops. The beneficial effects of a crop of clover upon subsequent grain crops was a matter of practical experience in ancient and mediæval times, and this empirical knowledge was applied more or less in the practice of agriculture during those periods, as well as in modern times. When the science of chemistry began to shed light upon the production of vegetable matter, and showed the relation which plants, soil and air bore to each other, and especially that certain elements contained in the soil and air were essential to vegetable growth, the peculiar properties of the legumes received early attention. It was soon learned that the leguminous plants were preeminently nitrogen-gatherers. Having accepted the conclusions of Boussingault in regard to free nitrogen as true, the teachers of agricultural chemistry were forced to explain this property of the leguminous plants in various ways. Besides the empirical observations, already alluded to, many comparative experiments were made which showed the beneficial effects of legumes on subsequent grain crops. As an example the experiment of von Wulffen may be cited. One half of a certain field was allowed to remain in bare fallow, while the other half was sown to yellow lupines. After the lupines had fully developed the whole field was plowed and sown to rye. The yield of the two halves was determined separately with the following results:

	Grain.	Straw.
After lupines	532.5 lb	1,072 lb
After bare fallow	322 lb	656.5 lb

Here was a total increase in grain and straw of 626 pounds on that half of the field which had been sown to lupines, while nothing from without had been added to it except sixty pounds of lupine seed. The results of this experiment also show, what was claimed above, that the independent, bacterial activity of the bare fallow fell far short of producing sufficient available plant food for a full crop of rye.

In seeking an explanation for this effect of the legumes, Boussingault determined the amount of refuse, *i. e.*, stubble and roots, left in the soil by various crops. For this purpose he had the roots, etc., collected

from measured plots of fields from which the crops had been harvested. His results are given in kilos per hectare and refer to dry matter. The nitrogen of the refuse was also determined. His figures are given in the following table:

	Crop.	Refuse.	Nitrogen of Refuse.
Wheat	1,002	518	2.1
Oats	1,608	650	2.6
Clover	1,975	1,547	27.9

If it be considered that the essential ash ingredients of plant food are equally high in the clover refuse, it will be seen that the manurial value of the clover refuse is out of all proportion to that of the two cereals, and consequently that clover must be a better forerunner for a grain crop than a grain crop itself. But Boussingault did not stop here. He also collected the refuse matter, roots and leaves from a crop of mangolds, and found that not only the dry matter, but also the nitrogen contained therein, was in excess of that of the clover. Here was a dilemma; for it was well known that, compared to legumes, root crops were poor forerunners for grain crops. The explanation for this apparent contradiction was found in extensive experiments made at Rothamstead. Laws and Gilbert raised root crops on the same field for years in succession without the application of manures, and found that they rapidly exhausted the surface soil. On the other hand, they showed that with clover, even after the removal of a highly nitrogenous crop, the soil was left richer in nitrogen than it was before. It is but fair to state in this connection that other investigators found much larger yields with clover than Boussingault. Thus, to take the other extreme, Heiden obtained from measured plots of clover, after it had become fully ripe, and by removing the whole aerial portion of the crop, the following results, expressed in kilos per hectare:

	Aerial Portion.	Roots.
Dry matter	14,548	8,469.6
Nitrogen	381.5	275.3

Laws and Gilbert, Heiden, and in fact all who investigated this subject explained this large accumulation of nitrogen principally by the assumption that clover, on account of its deep roots, had the power, in a marked degree, of obtaining a large portion of its food from the subsoil and bringing it to the surface. Furthermore, it was assumed that on account of the great leaf surface of clover, its more succulent nature and its longer period of growth, it was capable of collecting more ammonia from the air than was the case with grasses and cereals. Another peculiarity which the legumes were thought to possess was their ability to assimilate, in a higher degree than other crops, the reserve nitrogen of the soil. This assumption would explain, of course, why these plants should make a luxuriant growth on soils on which, for lack of available nitrogen, other crops failed to make a good stand, but it would not throw any light upon the fact, established by general observation, that the total fixed nitrogen of the soil was so materially increased.

It may be truthfully said that all these explanations taken together were not entirely satisfactory to those who were engaged in the teaching of agricultural chemistry, but, in short, this was the status of the nitrogen question for a generation or more, when Hellriegel announced before the section of agricultural chemists of the German Association of Men of Science and Physicians, at their meeting in 1886, that the leguminous plants could assimilate the free nitrogen of the air, and that this assimilation was intimately connected with the nodules appearing upon the roots of

these plants. The hearty applause with which this announcement was received at the meeting, and the widespread and spontaneous interest which it awakened all over the world, showed that it came as a relief to agricultural chemists and vegetable physiologists in general. The report of Hellriegel was based upon observations and experiments made during the four preceding years. He had been appointed jointly with Wilfarth as referee on the subject of nitrogen assimilation by plants. The experiments were made in pots containing four kilos of recently ignited sand, to which the proper amount of mineral plant food, free from combined nitrogen, had been added. The main points established were as follows:

1. When no combined nitrogen was added to the artificial soil the acquisition of nitrogen over that contained in the seeds was naught. This was true for all kinds of plants, including the legumes.

2. The development of all kinds of plants and the acquisition of nitrogen were in direct proportion to the amount of combined nitrogen added.

3. When a small quantity of natural soil, or of an aqueous infusion of such soil, was added to the contents of the pots and no other combined nitrogen introduced, the graminaceous plants, as well as some other families of plants, died of nitrogen starvation and their acquisition of nitrogen was naught.

4. Under the same conditions the leguminous plants, after a period of nitrogen starvation, began to recuperate, the foliage returned to its normal green color, and the plants continued to grow, in some cases vigorously, to complete maturity, and acquired all the nitrogen necessary for this development.

5. The graminaceous plants are dependent upon the combined nitrogen of the soil for their development.

6. The legumes are independent of the combined nitrogen of the soil and can acquire all the nitrogen for their complete development from the air, and, furthermore, not from the small quantity of combined nitrogen contained in the air, but from the *free* nitrogen.

7. Whenever, under these conditions, the legumes acquired nitrogen, this acquisition was invariably accompanied with the appearance of tubercles on their roots.

8. Sterilization of the natural soil or of the soil infusion destroys its effect.

A year later, 1887, Wilfarth made a further report on this subject. In one experiment made by Hellriegel and Wilfarth the classical method of Boussingault was employed. They placed into a large glass globe four kilos of ignited sand, mixed with sufficient water and the necessary mineral constituents of plant food free from nitrogen compounds. They also added a small quantity, an aqueous infusion, of a soil in which peas had been previously grown. In the artificial soil thus prepared they planted a pea, a grain of oats and a buckwheat seed. The globe was hermetically sealed with a ground-glass stopper and the necessary carbon dioxide for the growth of the plants was introduced from time to time. The oat and buckwheat plants grew only till the seeds had become exhausted, and acquired no nitrogen in excess of that contained in the seeds. On the other hand, the pea plant made a vigorous and normal growth and was still growing, when the report was made. A large part of this plant had been removed and was found to contain 6.55 grams of dry matter and 0.137 gram of nitrogen.

This interesting experiment not only corroborates the claims of these investigators, but it completes the original experiment of Boussingault, in that it restores the condition of natural soils, which he had de-

stroyed by his method of removing fixed nitrogen. In this connection it is of interest to refer again to the position on the nitrogen question occupied alone by Ville. It can readily be understood that, in the large apparatus employed by this investigator, the chances for complete sterilization were very remote, especially since no particular attention was paid to this point. Microbes from the soil could easily have found their way into his large case through dust or otherwise, and in the presence of organic matter arising from the seeds and the roots of the plants, could, in a short time, become active in fixing the free nitrogen of the air. The contention of Ville that, in his experiments, free nitrogen of the air was assimilated by plants may, therefore, have been sound.

But to return to the line of thought broken by this digression, Wilfarth reported some important gains in nitrogen by lupines grown in pots with four kilos of nitrogen-free sand on addition of a measured quantity of soil infusion containing not more than seven tenths of a milligram of fixed nitrogen. The yields are as follows:

WITH SOIL INFUSION:

No. 3. 44.73 grms. dry matter with 1.099 grms. nitrogen.

No. 4. 45.62 grms. dry matter with 1.156 grms. nitrogen.

No. 5. 44.48 grms. dry matter with 1.194 grms. nitrogen.

No. 6. 42.45 grms. dry matter with 1.337 grms. nitrogen.

WITHOUT SOIL INFUSION:

No. 9. 0.918 grms. dry matter with 0.0146 grms. nitrogen.

No. 10. 0.800 grms. dry matter with 0.0136 grms. nitrogen.

No. 11. 0.921 grms. dry matter with 0.0132 grms. nitrogen.

No. 12. 1.021 grms. dry matter with 0.0133 grms. nitrogen.

By the sole employment of a small quantity of soil infusion containing an infinitesimal amount of combined nitrogen, in pots holding about eight pounds of sand, the plants made an average gain in dry matter of 42.9 grams, and in nitrogen of 1.18 grams over the same kind of plants grown under the same conditions without this addition. This remarkable result was surely worthy of the general interest which its publication evoked.

Numerous experimenters all over the world at once began to pay attention to the little tubercles, and they were investigated from all points of view. Their morphology was studied by Frank, Laurent and others. For this purpose Frank, as well as Laurent, grew plants partly in water culture with the production of root tubercles. Since their labors belong to the domain of biology this simple reference to them here will suffice.

The results of all investigations from a chemical standpoint verified the conclusions reached by Hellriegel and Wilfarth. But, in addition to this, a great many new facts bearing upon this subject were obtained. Bréal analyzed the nodules of various legumes and found that the content of nitrogen in the dry matter varied from three to seven per cent., and was higher than that of any other part of the plants excepting the seeds. This fact is significant.

Bréal also obtained results similar to those of Hellriegel and Wilfarth by germinating peas between moistened filter papers, inoculating the roots, after they had attained the length of a few centimeters, with a needle which had been plunged into a tubercle, and then growing the plants in nitrogen-free sand containing the necessary mineral ingredients of plant food.

This investigator also grew peas in water culture. After germinating seeds between moistened filter papers as before,

and after the roots had attained a length of three or four centimeters he inoculated them with a needle which had been inserted into a tubercle of alfalfa, and placed two of the young plants in a culture jar, which contained a nutrient solution free from combined nitrogen. The peas grew regularly so long as they found nourishment in the cotyledons. Then a period of nitrogen starvation set in, after which the plants recuperated and grew to maturity with the production of fruit. The period of vegetation extended from April 2 to June 10. At the latter date the roots contained numerous tubercles. The stalks and roots were separated, dried at 110° C. and weighed. The nitrogen of both portions was determined, as was also the weight and nitrogen of two seeds similar to those used in the culture experiments. The following table gives the results:

	Dry Matter, Grams.	Nitrogen, Per Cent.	Nitrogen, Total.
Stalks	3.785	2.35	0.089
Roots	1.165	2.60	0.030
Total	4.95		0.119
Seeds	0.502	3.60	0.018
Gain	4.448		0.101

The table shows that the plants contained ten times as much organic matter and six and six tenths times as much nitrogen as the seeds from which they were derived; also that the percentage of nitrogen of the roots was greater than that of the aerial portion. Now when it is considered that, in this experiment, there was no nitrogen compound of any kind present, except the infinitesimal quantity introduced by puncturing the roots with the needle, and that in two small plants there was a gain of 101 milligrams of combined nitrogen, the claim for the assimilation of free nitrogen must be regarded as established.

The order of leguminous plants, therefore, occupies a unique position in the art of agriculture. The experimental evidence herein submitted shows conclusively why leguminous crops have for ages been recognized as being of special value in maintaining soil fertility, and the discussion of this subject points to the fact that, in many walks and practices of life, empiricism has been in advance of science.

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SCIENTIFIC BOOKS.

Glacial Formations and Drainage Features of the Erie and Ohio Basins. By Frank Leverett. U. S. Geol. Survey, Monograph XLI. Washington. 1902. Pp. 802; 26 pl. (maps, sections and views from photographs), and 8 figures in the text. $1.75.

Ohio is the central area described in this report, and it also includes parts of each of the adjoining states and of the Canadian province of Ontario. The great importance and interest of the glacial history of this region, early studied by Whittlesey, Newberry, Orton, Gilbert and N. H. Winchell, and later by Spencer, I. C. White, Wright, Claypole, Chamberlin, F. B. Taylor and many others, is indicated by about five hundred papers cited in a bibliography of twenty pages.

Mr. Leverett enumerates eleven epochs or stages of the glacial period, as follows: (1) The oldest recognized glaciation, called the sub-Aftonian by Chamberlin, perhaps the same as the Albertan of Dawson; (2) the Aftonian interval of recession of the ice sheet; (3) the Kansan stage of glacial readvance; (4) the second or Yarmouth interval of recession; (5) the Illinoian readvance; (6) the third or Sangamon recession; (7) the Iowan readvance, with the principal time of deposition of the loess; (8) the fourth or Peorian recession; (9) the early Wisconsin stage of readvance, with the formation of four successive systems of marginal moraines during the early part of the ensuing recession; (10) the fifth interval of glacial retreat,